FINAL REPORT
to

NOAA'S HUMAN DIMENSIONS OF GLOBAL CHANGE RESEARCH (HDGCR) PROGRAM

PROJECT TITLE: Climatic Variations and the International Management of the North American Pacific Salmon Fishery: A Game Theoretic Perspective

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NOAA/OGP Grant NA86GP0219 (Proposal # GC98-122)

PERIOD OF PERFORMANCE:

June 1998 - May 2003

I. OVERVIEW

A. PROJECT ABSTRACT

Pacific Salmon are anadromous fish that migrate across interstate and international boundaries in their oceanic migrations. Fish spawned in the rivers of one jurisdiction are vulnerable to harvest in other jurisdictions. Because such interceptions are inevitable, the United States and Canada have long attempted to cooperatively manage Pacific salmon harvests. Their efforts, however, have been stymied by repeated disagreements and by episodes of aggressive competitive harvesting. The most recent breakdown in cooperation began in 1993 when Canadian and U.S. representatives on the Pacific Salmon Commission failed to agree on a set of mutually acceptable harvesting regimes under the terms of the 1985 Pacific Salmon Treaty. The ensuing six year period of conflict was marked by over-harvesting of fragile components of the resource, growing acrimony, and inflammatory rhetoric. One of the central factors contributing to the dispute was a change in the balance of U.S. and Canadian interceptions of one another's salmon that was linked to dramatic improvements in survival rates and abundance of northern salmon stocks, while southern salmon stocks plummeted. It is now widely accepted that those changes in abundance were strongly driven by the effects of climatic changes on the marine environment. However, the parties to the dispute had initially failed to recognized the significance of environmental variability, and had given little attention to the need to accommodate such changes.

This project describes the evolution of the institutional framework for U.S./Canadian cooperation on Pacific salmon management, and documents the role of climatic regime shifts on the two nations' efforts to maintain cooperation. In addition, the project employs conceptual game theoretic models to explain the course of the conflict and to describe the significance of particular treaty provisions and existing rules governing bilateral negotiations. In addition, with the aid of these models, the project evaluates the prospects of the revised management framework established by the 1999 Pacific Salmon Agreement.

The final stage of the project entailed developing a mathematical model of the international fishery game to simulate the effects of stochastic changes in stock productivity and/or migratory behavior in the context of varying levels of scientific understanding and ability to forecast those changes. The simulation results demonstrate that improved scientific information can be valuable when cooperation prevails, but it can be highly destructive when two nations are harvesting competitively. In the latter case, improved predictability can lead to a more rapid race to "the tragedy of the commons." This effect is especially pronounced when the resource itself is fragile, in the sense of being characterized by low reproduction rates and slow growth. On the hopeful side, the simulation results demonstrate that the gains from cooperation can be very large in some cases. This suggests that improved scientific information might foster cooperation by generating a large potential "cooperative surplus."

A. OBJECTIVE OF RESEARCH PROJECT

This project was motivated by the recent period of intense conflict between the U.S. and Canada over management of Pacific Salmon harvests. The members of the research team hypothesized that climate-related changes in salmon abundance and migratory behavior, together with limited scientific understanding and conflicting interpretations of those effects had contributed to the conflict. The following question naturally arose: Could this dispute have been forestalled, or solved sooner if better information had been available about the impacts of climate variability, and if there had been better forecasts of those impacts?

This project had two complementary goals. The first was to document the impacts of environmental variability and the role of scientific information in the case of the Pacific Salmon dispute. The second was to analyze the effects of stochastic natural variability in formal game-theoretic models of shared international fisheries and, in particular, to examine the effects of varying the quality of forecast information in such a game.

B. APPROACH

The research entailed the following components: 1) analysis of the history of conflict and cooperation in the Pacific salmon case; 2) development of simple conceptual game models pertinent to the Pacific salmon case; 3) development of a mathematical stochastic, dynamic fishery game model for use in simulations; 4) simulation experiments to examine the effects of different specifications of model parameters and to address the question of the value of improved forecasts. Because the project commenced in the context of ongoing negotiations and a rapidly changing institutional environment, Drs. Miller and Munro focused considerable effort on tracking the negotiations and documenting the evolving strategies and stated goals and beliefs of the various parties having a stake or voice in the process. While that work was ongoing, Dr. McKelvey began work on the mathematical modeling and simulation components of the project. Work on these elements progressed as parallel, mutually reinforcing projects.

C. DESCRIPTION OF MATCHING FUNDS

This project facilitated a very productive collaboration among the co-PI's and with other project participants, especially Gordon Munro, project consultant. The NOAA funding covered only part of the team's work in this area. NCAR was able to co-sponsor Dr. Miller's efforts by funding a significant fraction of the work time that she spent on the project. Similarly, Dr. McKelvey spent considerably more time on the project than was actually covered by NOAA funds. As described below, the NOAA funded project benefitted considerably from interaction with Dr. McKelvey's NSF-funded project. In addition, one of the group's major publications (Miller, et al., 2001) benefitted from the contributions of an unfunded collaborator, Ted McDorman, Professor of Law, University of Victoria. Thus, the NOAA funding leveraged a much larger effort.

I. INTERACTIONS

A. DECISION-MAKERS

As noted above, the team interviewed a number of decision-makers over the course of the project. The following individuals were interviewed at length – either in person or by telephone. In addition several of these interviewees graciously agreed to multiple follow-up conversations, return visits and e-mail exchanges. The list includes senior policy makers, stake-holders, Pacific

Salmon Commissioners, members of various Commission Panels and Technical Committees, and Commission staff.

Interview list:

Sandy Argue – Department of Fisheries and Oceans Canada, Vancouver, B.C.

Dennis Austin – Washington Department of Fish and Wildlife, Olympia, WA

Tom Bird – Sport Fishing Institute of British Columbia, Vancouver, B.C.

Jim Blick – Alaska Department of Fish and Game, Juneau, AK

Dave Cantillon – NOAA- NMFS, Seattle, WA

Pat Chamut – Assistant Deputy Minister-Operations, Department of Fisheries and Oceans Canada, Ottawa, Ontario (Pacific Salmon Commission Vice-Chair 1999-2000)

Kevin Duffy – Alaska Department of Fish and Game, Juneau, AK

Fred Fortier – Aboriginal Fisheries Commission, Vancouver, B.C.

Dave Gaudet – Alaska Department of Fish and Game, Juneau, AK

Bud Graham – Assistant Deputy Minister, B.C. Provincial Ministry of Fisheries

Jeff Hartman – Alaska Department of Fish and Game, Juneau, AK

Blair Holtby – Research Scientist, Pacific Biological Station, Department of Fisheries and Oceans Canada, Nanaimo, B.C.

Dr. Jim Irvine – Research Scientist, Pacific Biological Station, Department of Fisheries and Oceans Canada

Don Kowal – Executive Secretary, Pacific Salmon Commission, Vancouver, B.C.

Dr. Gerry Kristianson – Pacific Salmon Commissioner and North Pacific Anadromous Fish Commissioner, Vancouver, B.C.

Don McRae – University of Ottawa, Faculty of Law (Former Head of Canadian Negotiation Team)

Gary Morishima – Quinault Management Center, Mercer Island, WA

Dr. Brian Riddell – Research Scientist, Pacific Biological Station, Department of Fisheries and Oceans Canada, Nanaimo, B.C.

William Ruckelshaus – Advisor to U.S. and Canadian Federal Governments on Pacific Salmon Dispute, Seattle, WA

Leon Shaul – Alaska Department of Fish and Game, Juneau, AK

Curt Smitch – Governor's Salmon Recovery Office, State of Washington, Olympia, (Pacific Salmon Commission Chair 1999-2000)

Mr. Paul Sprout – Director General, Special Projects, Department of Fisheries and Oceans Canada, Ottawa, Ontario

Ben VanAlen – Alaska Department of Fish and Game, Juneau, AK

Chuck Walters – NOAA - NMFS, Seattle, WA

Dr. James C. Woodey - Chief Biologist, Fisheries Management Division, Pacific Salmon Commission

In addition, members of the research team engaged in many short meetings and informal conversations with individuals who have specialized knowledge of Pacific salmon management issues. Among the many people with whom we spoke, we obtained particularly valuable information and insights from the following individuals:

James J. Anderson – University of Washington, School of Fisheries, Seattle, WA

Xan Augerot – The Wild Salmon Center, Portland, OR

Richard Beamish – Pacific Biological Station, Department of Fisheries and Oceans Canada, Nanaimo, B.C

Eugene H. Buck – Senior Analyst in Natural Resources Policy, Congressional Research Service, Washington D.C.

Colin Clark – Mathematics Department, University of British Columbia, Vancouver, BC

Jim Crutchfield – Natural Resources Consultants, Friday Harbor, WA

Robert Francis – School of Fisheries, University of Washington, Seattle, WA

Steven Globerman – Western Washington University, College of Business and Economics, Bellingham, WA

Dan Huppert – School of Marine Affairs, University of Washington, Seattle, WA

Cameron MacKay – Department of Foreign Affairs and International Trade, Ottawa, ON

Nathan Mantua – JISAO (Joint Institute for the Study of the Atmosphere and the Oceans), University of Washington, Seattle, WA

James Norris – Marine Resources Consultants, Port Townsend, WA

Clair Parker - AquaStar Inc., and Northwest Fisheries Association, Seattle, WA

Patrick Patillo – Pacific Salmon Commission, Vancouver, BC

Larry Rutter – National Marine Fisheries Service, Lacey, WA

Mike Sheppard – Michael Shepard and Associates, Ltd., Victoria, BC

John Skidmore – Bonneville Power Administration, Portland, OR 97208-3621

Ted Strong – Columbia River Inter-Tribal Fish Commission, Portland, OR

Orri Vigfusson – North Atlantic Salmon Fund, Reykjavik, ICELAND

John Volkman – National Marine Fisheries Service, Portland, OR

Brad Warren – Editor, Pacific Fishing Magazine, Seattle, WA

Warren Wooster – School of Marine Affairs, University of Washington, Seattle, WA

D. CLIMATE FORECASTING COMMUNITY

This project did not require extensive interaction with members of the climate forecasting community, although Dr. Miller remained in contact with NCAR researchers engaged in ENSO analysis and forecasting work. The team found that the level of understanding of the impacts of climate variability on salmon populations is still so rudimentary that considerable further research is needed just to understand those linkages. In addition, all of the evidence suggests that the smolt stage - one to several years before harvest is the most critical period. It is at that period that large-scale climate variability associated with ENSO or the Pacific Decadal Oscillation (PDO) has significant impacts on subsequent salmon abundance. Thus, climate forecasts *per se* are likely to be less useful than good observations of near-shore marine and estuary conditions at the time of smolt emergence.

E. OTHER PROJECTS SUPPORTED BY NOAA CLIMATE AND SOCIETAL INTERACTIONS DIVISION

Dr. Miller consulted on several occasions with members of the University of Washington RISA team. In particular, Nathan Mantua and Robert Francis provided valuable insights on their research concerning the effects of the PDO on North American salmon populations. The project also benefitted from conversations with Richard M. Adams, Chris Costello and David Sampson who had worked on an earlier project on the value of ENSO forecasts for management of Pacific Northwest salmon that was funded by NOAA OGP's Economics and Human Dimensions program.

II. ACCOMPLISHMENTS

A. RESEARCH TASKS

Historical Analysis and Application of Conceptual Game Models

Principal Investigator, Dr. Kathleen Miller and project consultant, Dr. Gordon Munro took the lead on the historical and institutional analysis portion of the project. In consultation with Dr. McKelvey, they also incorporated the conceptual game models in the analysis. The work entailed an extensive literature review, analysis of harvest records, and numerous interviews, both in-person and via telephone and e-mail.

The interviews included: Pacific Salmon Commission members; biologists, fishery managers and high-level policy makers in state, provincial, and U.S. and Canadian federal agencies; academic researchers; and members of commercial, sport and Native American / First Nations fishing communities. The research team collated and synthesized information from the interviews and literature review, and integrated it with the conceptual game model to examine the effects of a climatic regime shift on the incentive structure of the Pacific salmon management game. In addition, the team examined the tension between environmentally-driven shifts in the strength of the parties' bargaining positions, and concepts of "equity"-- as expressed in the language of the Treaty. Finally, the project drew upon evidence from fisheries in other parts of the world to assess options for maintaining cooperation in the face of environmental variability.

Peter Tyedmers, a University of British Columbia graduate student funded by the project, made substantial contributions to this part of the project. Other project-funded graduate students: Stephanie McWhinnie (UBC), Gorazd Ruseski (UBC) and Greg Larson (U. of Colorado) also performed essential research tasks.

The team wrote several papers reporting on this phase of the research (see list below). The most important of these is: **The 1999 Pacific Salmon Agreement: A Sustainable Solution?** (Miller et al., 2001). This paper provides a detailed description of the history of the Pacific salmon dispute, together with an analysis of international fisheries law pertinent to this case. The paper also describes the application of game theoretic concepts to understanding the role of climate-related changes in abundance and migratory patterns in the history of

U.S./Canadian Pacific salmon management. Insights from game theory are then used to evaluate the strengths and potential pitfalls of the new (1999) Salmon Treaty Agreement. This paper was published by the University of Maine's Canadian-American Center as part of the Center's Canadian-American Public Policy Occasional Paper series. The Center strongly encouraged submission of this paper, because of the importance and timeliness of the topic and the strong reputation of the research team. In addition, the Center ensured that the paper was widely distributed to a targeted audience of policy makers, fishery managers, stakeholders and members of the research community. The research team supplied the Center with a list of such individuals. The Center mailed copies to the 165 individuals on that list in addition to their regular subscribers. This enabled the research team to immediately put the results of the NOAA-funded project in the hands of top policy makers and to provide an expression of thanks to the many interviewees and others who had assisted the team's fact-finding efforts.

The most recent publication arising from this phase of the work is: **North American Pacific Salmon: A Case of Fragile Cooperation** (Miller, 2003). This paper was requested by the Food and Agriculture Organization of the United Nations (FAO) and was presented at the Norway-FAO Expert Consultation on the Management of Shared Fish Stocks, Bergen, Norway – 7-10 October 2002. It was published as part of the Consultation Report. The Expert Consultation enabled the NOAA-funded team to provide direct input to high-level deliberations on international policy design.

Mathematical Model Development and Simulation

The mathematical modeling / simulation portion of the project was led by Dr. Robert McKelvey, who worked to develop a stochastic dynamic game model of a trans-boundary marine fishery reflecting important features of the North American Pacific salmon fisheries. The "stochastic split-stream model" that Dr. McKelvey developed for this project, mimics the variable (climate-driven) split in the return migration of Fraser River sockeye salmon around Vancouver Island. Specifically, the model is designed so that only a portion of the run is accessible to each nation's fleet, and that fraction varies stochastically through time. This mirrors the variable Johnstone Strait diversion rate. Historically, that diversion rate was low, causing the majority of Fraser River sockeye to pass within the reach of the U.S. fleet. In recent years, however, warm conditions have caused a large fraction of the run to return through Johnstone Strait – around the north end of Vancouver Island, thus staying in Canadian waters. This change significantly strengthened Canada's bargaining position with respect to harvests of the Fraser River stocks. As one of the most important salmon fisheries shared by the U.S. and Canada, understanding the effects of environmental variability in the Fraser River case is central to understanding the overall bi-national salmon management problem.

Because of limitations of time and budget, it was decided to adapt the classic Levhari-Mirman common pool "Fish War" model (Bell J. Econ, **11**, 322-344, 1980) to these circumstances. The specific model structure that was chosen, involving risk-averse utility functions and a power-law stock-recruitment relation (or biological growth function) permitted significant simplifications in obtaining the Nash-equilibrium solutions of the harvesting games. Namely, the equilibrium policy pair could be numerically obtained by solving a closed-form system of algebraic equations. From this the payoff functions could be approximated either by simulation or by direct reduction of explicit multi-integrals.

Dr. McKelvey, worked with Greg Cripe (a University of Montana graduate student funded by this project) to develop a suite of numerical and simulation programs, to implement the solution and payoff approximation procedures. These programs run on MATLAB version 5.3 R11 or later. The optimization toolbox is needed. Results of this work have been published as NCAR Technical Reports (McKelvey, 2001; McKelvey and Cripe, 2001), and insights from this effort were incorporated in the other project publications.

B. SYNOPSIS OF KEY RESULTS (also see attached powerpoint slides - Appendix)

Historical Analysis and Application of Conceptual Game Models

- The 1977 climatic regime shift contributed to a change in the return migration path of Fraser River sockeye salmon around Vancouver Island, so that a larger fraction of the run remained entirely in Canadian waters. Canada took advantage of this situation in the negotiations leading to the 1985 Pacific Salmon Treaty to press for a more favorable division of the anticipated harvest.

- Persistent warm coastal conditions also contributed to dramatic increases in Alaskan salmon abundance while survival conditions for southern salmon stocks were generally poor, particularly during the1990s.

- Uncertainty as to the causes of changing abundance played a role in the dispute, in that blame-laying was a significant part of the rhetoric over the course of the disagreement.

- The benefits that harvesters in Washington, Oregon and Southern British Columbia had expected to reap from the 1985 Treaty never materialized. Instead, declining smolt survival rates put the Treaty's stock rebuilding objectives out of reach.

- In addition, the balance of interceptions shifted in favor of the U.S. – As Alaskan harvests increased in response to increased abundance of Alaskan salmon, Alaska also harvested more Canadian salmon that were intermingled with the Alaskan stocks. Canada could not redress the imbalance without further imperiling the declining southern salmon stocks.

- This imbalance became increasing problematic because the members of the Pacific Salmon Commission did not consider side payments as an option for sharing the benefits of the fishery. In addition, rigid positions taken by some of the participants in the regime negotiations called for uncompensated sacrifices on the part of other parties, and thus ignored "individual rationality." The parties attempted – and ultimately failed – to balance multiple conflicting objectives using commercial harvest shares as their only tool.

- The resulting tensions escalated into full-blown conflict in 1993, and a six-year period of deadlock ensued during which the U.S. and Canada failed to agree on a full set of fishing regimes for the stocks governed by the Treaty.

- The impasse was broken only after Canadian concerns about the declining health of some of their own salmon stocks led to a significant shift in Canadian bargaining objectives – away from insistence on a narrow interpretation of “equity” and towards a focus on conservation.

- The 1999 Pacific Salmon Agreement, which amends the Pacific Salmon Treaty has introduced the important innovations of “abundance-based” management and implicit side payments in the form of U.S. contributions to two Endowment Funds. This will promote conservation by allowing harvest shares to track changes in abundance and will provide more flexible options for sharing the benefits of the fishery.

- However, scientific uncertainties about estimates of stock abundance could contribute to future conflicts unless the estimates are based on impartial scientific input.

Mathematical Model Development and Simulation

- Simple conceptual game models can be used to demonstrate how environmental variability can destabilize cooperation by causing “threat-point” payoffs to change.

- However, to address questions relating to the impacts of uncertainty and the value of improved information, a formal stochastic dynamic model of the fishery game is needed.

- This project extended the current theoretical literature on such games by building the "stochastic split stream" model, which allows explicit consideration of the effects of incomplete and possibly asymmetric information about stochastic environmental variables.

- Specifically, the model mimics the important Fraser River sockeye fishery, in that a single breeding stock splits into two sub-populations as it passes through the fishing grounds, with each sub-population accessible to only one of the competing fleets. The fraction of the stock available to each fleet varies stochastically. The recruitment function (i.e., the relationship between size of the spawning stock and size of the subsequent offspring generation) also varies in response to changing environmental conditions.

- Model simulations were performed, examining competitive and cooperative game outcomes under various assumptions regarding the quality of information available to the players and the degree of asymmetry in access to that information.

- These simulations considered cases in which the fraction of the stock available to each fleet is stochastic. Variability in the recruitment function was considered by comparing outcomes for highly productive, moderately productive, and low productivity recruitment functions.

- Simulation results suggest that when there is a climatic regime shift that causes the average split to change to the advantage of one of the fleets, payoffs increase for the environmentally advantaged player and decrease for the disfavored player.

- The simulations also indicate that environmentally advantaged player will be better off with cooperation than without. So it is in that player’s interest of to seek to maintain cooperation.

- For the particular model structure considered, the simulations demonstrate that improved information is always valuable **if cooperation prevails**. However, if the fleets are engaged in a non-cooperative harvesting game, improved information could merely contribute to a more intense race to the tragedy of the commons. Under some circumstances, improved information could lead to reduced payoffs to the fleets, and significant declines in the biological health of the resource (i.e. smaller escapements and thus smaller subsequent recruitment).

- The potential damage from competitive harvesting also depends on the price of harvested fish relative to cost of harvesting and on the biological characteristics of the resource itself. Competitive harvesting is most damaging when the resource is high priced, relatively easy to harvest, and fragile in the sense of being characterized by low recruitment rates and slow stock growth. It is in those cases that improved forecast information can do more harm than good.

- However the difference between cooperative and competitive payoffs (the cooperative surplus) also tends to be largest in those cases. Because better forecast information would increase the potential gains from cooperation, it might serve as a stimulus for cooperation. Our model, however, does not address the process of moving from competition to cooperation, so this is a question that requires further investigation.

C. DISCUSSION OF KEY FINDINGS

Historical Analysis and Application of Conceptual Game Models

The project found that 1977 Climate Regime Shift contributed to two periods of conflict between the U.S. and Canada, each entailing episodes of competitive harvesting of Pacific salmon.

The first period of conflict coincided with on-going negotiations leading to the 1985 Pacific Salmon Treaty, during which a dramatic increase in the average Johnstone Strait diversion rate allowed Canada to take advantage of its significantly strengthened bargaining position. Despite that experience, there is little evidence that potential impacts of climate variability on salmon stocks received significant consideration in the negotiations leading to the 1985 Pacific Salmon Treaty, or indeed until long after cooperation under the terms of the Treaty had collapsed. The second period of conflict ran from 1993 to 1998 and revolved around a dispute over the equitable division of harvest benefits.

The 1985 Treaty proved to be ill-designed to manage the persistent effects of the climate regime shift on harvesting opportunities and incentives to cooperate. In particular, there were unresolved tensions between equity objectives and the individual rationality positions of the parties to the Treaty. The fishing regime-setting process embodied in the Treaty was not sufficiently flexible to resolve those tensions – especially given the negotiators' focus on commercial fisheries and on attempting to balance harvest benefits without use of side payments – i.e., using only "harvest-ceilings" to equalize the balance of interceptions. That approach failed because robust fisheries in Southeastern Alaska led to increased Alaskan interceptions of Canadian salmon, while rapid declines in southern stocks made it impossible for Canada to maintain its perceived "fair share" of the interceptions without further imperiling those stocks. A resolution to the conflict came only after the parties finally recognized the need to take natural fluctuations in stock abundance into account, and after significant declines in the status of some of Canada's southern salmon stocks led to a radical shift in Canadian bargaining objectives. These changes contributed to a new willingness to consider more flexible alternatives for balancing the benefits of the shared resources, including use of implicit side payments. In addition, the new approach of basing harvest shares on mutually accepted indices of abundance, now explicitly recognizes the importance of responding to the effects of natural, climate-related variability in stock abundance.

Mathematical Model Development and Simulation

As noted above, Dr. McKelvey developed the stochastic split stream model (McKelvey, 2001) and worked with Greg Cripe to develop a suite of numerical and simulation programs, to implement the solution and payoff approximation procedures (McKelvey and Cripe, 2001). The output variables of interest are:

W1, W2 (the welfare levels for players 1 and 2);

H1, H2 (the total number of fish harvested by each of the two fleets; total harvest H = H1 + H2);
h1,h2 (harvest fraction selected by each player for the portion of the stock in its stream);

S (spawning escapement);

R (total recruitment of adult salmon accessible for harvest by the two fleets).

The values taken by these variables change over time as climate-related changes in the marine environment cause the productivity characteristics and/or the migration path of the returning adult salmon to vary. This model structure proved flexible enough to incorporate a variety of information structures, and model simulations show very clearly the role of uncertainty.

However the Levhari-Mirman formulation is in certain respects restrictive — for example it does not permit exploration of differing attitudes toward risk by the parties, or the influence of specific stock demographics on the evolution of the fishery. Hence it has not proved entirely adequate, particularly as a tool for comparing the effectiveness of alternative institutional structures for responding to the pervasive climate-related environmental shifts.

While this NOAA sponsored work was going on, Robert McKelvey was also engaged in a somewhat parallel project, funded by NSF. In 1998-2001 this project centered on game-theoretic analysis of multi-national management of highly migratory fish stocks, like tuna and swordfish, which are harvested in the Extended Economic Zones (EEZs) of many widely separated countries, and also in high seas international waters. Coordinated fishery management is required to be carried out through multinational Regional Fisheries Management Organizations (RFMOs), as mandated by the 1995 UN Agreement on Straddling and Highly Migratory Stocks, but the responsibilities and powers of the RMFOs, and mechanisms to make these effective, are still evolving.

By summer 2000, the modeling in the NOAA salmon project had already demonstrated the importance of asymmetric information in the stability of international fisheries treaties, so it was decided to model these effects upon the RFMOs. However it was recognized that the Levhari-Mirman model framework was too restrictive. Accordingly, Dr. McKelvey and his colleague Dr.Peter Golubtsov undertook to build a more flexible model, recognizing that, lacking the analytical simplifications inherent in the Levhari-Mirman structure, this would be a major analytical and computer programming task. By the end of summer 2001, *Version 1* of the McKelvey-Golubtsov model (MG1) was formulated and programmed, with the final write-up submitted for publication in January 2002: Robert McKelvey and Peter Golubtsov: *The Effects of Incomplete-Information in Stochastic Common-Stock harvesting Games (30 pp).*

Drs. McKelvey and Miller drew heavily upon both the historical analysis funded by the NOAA project and the modeling work funded by the NSF project to collaborate on a paper with Dr. Golubtsov: *Fish-Wars Revisited: A Stochastic Incomplete-Information Harvesting Game,* which is scheduled to be published in 2003 as part of an edited book. The above bullets (Section III. B.), are based on the findings in that collaborative paper, and thus reflect both NOAA and NSF funded efforts, as well as considerable unfunded research time contributed by Drs. McKelvey and Golubtsov.

The two models: MG1 (funded by NSF) and McKelvey-Cripe (MC) (generated by this NOAA project) give complementary views of the harvesting game. Neither model ultimately is superior to the other, each has potential advantages over the other and both deserve further development. While MG1 escapes the limitations in MC of specific stock-growth and harvest-payoff functional types, it still lacks the ability of MC to incorporate random elements simultaneously in both of these. A particular advantage of the MC model is the fact that the recruitment function can be made stochastic. In addition, MC has greater flexibility in its specification of information structures —allowing each fleet to possess information that is denied to the other. Recently, Dr. McKelvey and Greg Cripe have continued their work on the MC model (on an unfunded basis) to examine the impacts of simultaneous variability in both recruitment and stock-split. Analysis of those simulation results is ongoing. In addition, the upgraded MC2, which will be finished this summer, will also incorporate a new numerical algorithm for finding "**h**"(harvest fraction selected by each player for the portion of the stock in its stream). This will allow intuitive insights into the relative harvest levels of 1) the competitive game with separate observations, 2) the competitive game with transparency, i.e. shared observations, and 3) the cooperative game with shared information.

D. PUBLICATIONS AND PRESENTATIONS

Publications:

McKelvey, R., K. Miller and P. Golubtsov, “Fish-Wars Revisited: A Stochastic Incomplete-Information Harvesting Game,” in Justus Wesseler, ed., *Risk, Economic Response and the Environment,* Edward Elgar, *In Press*.

McKelvey, R. and K. A. Miller, 2002. "The Pacific Salmon Dispute: Rationalizing a Dysfunctional Joint Venture," in K. D. Lynch, M. L. Jones and W. W. Taylor, eds., *Sustaining North American Salmon: Perspectives Across Regions and Disciplines,* American Fisheries Society, Bethesda, MD.

McKelvey, R. and K. Miller, 2002. "A Stochastic Split-Stream Harvesting Model: Insights on Information and the Pacific Salmon War," Proceedings of the International Conference on Risk and Uncertainty in Environmental and Resource Economics, Wageningen, Netherlands, June 2002.

McKelvey, R., 2001. *The Split-Stream Harvesting Game I: Mathematical Analysis,* NCAR Technical Report, NCAR/TN-449+STR - Part I..

McKelvey, R., and G. Cripe, 2001. *The Split-Stream Harvesting Game II: Numerical and Simulation Studies*, NCAR Technical Report, NCAR/TN-449+STR - Part II.

Miller, K. A. “International Salmon Management: Challenges and Tools,”in Xanthippe Augerot, ed., *Atlas of the North Pacific Salmon Ecosystem,* The Wild Salmon Center, Portland, OR. *In Press*.

Miller, K. A., 2003. “North American Pacific Salmon: A Case of Fragile Cooperation” in FAO Fisheries Report No. 695 Supplement: Papers presented at the Norway-FAO Expert Consultation on the Management of Shared Fish Stocks, Bergen, Norway – 7-10 October 2002, pp. 105-122. FAO, Rome.

Miller, K. A. and G. R. Munro, 2002. "Cooperation and Conflict in the Management of Transboundary Fishery Resources," Proceedings of the Second World Congress of Environmental and Resource Economics, Monterey, CA June 2002.

Miller, K. A., G. R. Munro, T. L. McDorman, R. McKelvey and P. Tyedmers, 2001. *The 1999 Pacific Salmon Agreement: A Sustainable Solution?* Canadian – American Public Policy Occasional Paper, No. 47. Canadian – American Center, University of Maine, Orono, ME.

Miller, K. A., G. Munro, R. McKelvey and P. Tyedmers, 2001. “Climate, Uncertainty and the Pacific Salmon Treaty: Insights on the Harvest Management Game,” in *Microbehavior and Macroresults: Proceedings of the Tenth Biennial Conference of the International Institute of Fisheries Economics and Trade*, *July 10-14,2000, Corvallis, Oregon, USA*. Compiled by Richard S. Johnston and Ann L. Shriver. IIFET, Corvallis.

Presentations

October 2002 K. A. Miller – NOAA Office of Global Programs, Human Dimensions of Global Change Research, Principal Investigators Meeting, Seabrook Island, South Carolina, “Climate Variations and the International Management of the North American Pacific Salmon Fishery: A Game Theoretic Perspective.”

October 2002 K. A. Miller – Norway-FAO Expert Consultation on the Management of Shared Fish Stocks, Bergen, Norway, “North American Pacific Salmon: A Case of Fragile Cooperation”

June 2002 R. McKelvey and K. A. Miller – International Conference on Risk and Uncertainty in Environmental and Resource Economics, Wageningen, Netherlands, "A Stochastic Split-Stream Harvesting Model: Insights on Information and the Pacific Salmon War."

June 2002 G. Munro and K.A. Miller – Second World Congress of Environmental and Resource Economics, Monterey, CA, “Cooperation and Conflict in the Management of Transboundary Fishery Resources.”

October 2001 K. A. Miller – Colorado State University Chapter of the American Fisheries Society "The 1999 Pacific Salmon Agreement: A Sustainable Solution to the Management Game?"

September 2001 K. A. Miller – Institute for Behavioral Sciences, University of Colorado, Boulder, “The 1999 Pacific Salmon Agreement: A Sustainable Solution to the Management Game?

October 2000 K. A. Miller – Joint University of British Columbia, University of Washington Conference, Rethinking the Line: The Canada U.S. Border, Vancouver, B.C. “Climate, Uncertainty and the Pacific Salmon Treaty: Insights on the Harvest Management Game.”

July 2000 K. A. Miller – Tenth Biennial Conference of the International Institute of Fisheries Economics and Trade, Corvallis, OR. “Climate, Uncertainty and the Pacific Salmon Treaty: Insights on the Harvest Management Game.”

April 1999 K. A. Miller – NOAA/OGP Symposium on Human Dimensions, Tucson, AZ “Climate and the Pacific Salmon Dispute — Modeling the Implications of Divided Authority.”

September 1998 K. A. Miller – Northwest Fisheries Association, Seattle, WA, “Climate, Salmon Stocks and the Pacific Salmon Treaty.”

July 1998 K. A. Miller – Workshop on the Art and Science of Model-Building, University of Montana, Missoula, MT, "Context for Modeling the Pacific Salmon Treaty Game."

IV. RELEVANCE TO THE FIELD OF HUMAN-ENVIRONMENT INTERACTIONS

This project demonstrates that effective adaptation to climate variability often is not a simple matter. Adaptation is difficult when a resource is exploited by multiple competing users who possess incomplete information. If, in addition, their incentives to cooperate are disrupted by the impacts of the climatic variation, dysfunctional breakdowns in management rather than efficient adaptation may ensue. In this context, the research demonstrates that individual rationality plays a powerful role in the course of negotiations over the management of shared climate-sensitive resources.

Climate-related shifts in threat point payoffs can strengthen the bargaining position of one party relative to another, creating an incentives to take advantage of the altered environmental condition. Strongly-held beliefs about the equitable division of a resource also play a powerful role. Tension is likely to be present between equity objectives and power, in that it may be very difficult to simultaneously fulfill expectations regarding equitable allocation, and to accommodate shifts in threat point payoffs. Explicit attention to incorporating side payments and pre-negotiating strategies for responding to long-term climate-related changes in the resource may be needed to provide adequate flexibility to prevent the break-down of cooperative management agreements.

Conflict appears to slow the process of learning about the impacts of climate variations on the contested resource, as the opposing interests may adopt different interpretations of the causes of a change in the behavior or abundance of the resource. Arrangements for incorporating impartial, third party, scientific advice in management of a shared resource may therefore be an important element in efforts to maintain effective cooperative management.

The work further demonstrates that improved information is not always beneficial. If the resource is being exploited competitively, more accurate forecasts could hasten the decline of the resource and reduce payoffs to the competing resource users. This suggests that the value of scientific research to improve predictions of the abundance and location of a shared natural resource depends heavily on the amount of effort given to designing and maintaining robust cooperative management agreements. The research also suggests that the potential value of improved forecasts can be very large when the resource is being managed cooperatively, and that both the biological characteristics of the resource and the value of harvested units strongly affect the payoffs to cooperative as opposed to competitive harvesting.